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The Use of Fiber-Reinforced Polymer-Matrix Composites in Army Ground Vehicles

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ABSTRACT

Polymer-matrix composites have been researched and studied for over 20 years regarding their applications to Army ground vehicles. Although much research has been performed only a few fiber-reinforced polymer-matrix composites are actually in service today. Evolving vehicle requirements however, will necessitate the implementation of these composites. This paper provides information regarding past, present and future applications for fiber-reinforced polymer-matrix composites.

INTRODUCTION

Tactical vehicle components have traditionally been composed of steel and/or aluminum. The use of these materials however, has resulted in a high incidence of component failure, resulting in reduced vehicle life (Weidig). In response to this, the Army began assessing the use of advanced materials. Research ranges from the replacement of vehicle parts or components to the replacement of structure and armor. These advanced materials will provide the solider with stronger, light weight vehicles, that can out-last and out-perform their metallic counterparts.

POLYMER COMPOSITE BACKGROUND

VEHICLE REQUIREMENTS

The performance requirements for tactical ground vehicles are extremely demanding. Vehicle requirements include mobility, reliability, survivability, transportability and the ability to handle all types of environmental conditions (Weidig).

There are several factors that must be taken into consideration when choosing a polymer composite. They include cost, ease of fabrication, material availability, reparability, strength, weight, flammability, corrosion resistance and fatigue resistance. Also, polymer composites must be able to withstand environmental aspects including temperature, mud, dust, dirt, sand, snow, rocks, road debris, nuclear, biological and chemical (NBC) agents and decontaminants (Weidig, Pivitt).

VEHICLE COMPONENT PROBLEM AREAS

Research was performed regarding component problems on the following vehicles: the High Mobility Multi-Purpose Wheeled Vehicle (HMMWV), three different types of medium tactical vehicles (MTV), the heavy expanded mobility tactical truck (HEMTT), and the M1A2 Abrams battle tank. Studies were initiated to determine if polymer composites would provide benefits over steel without compromising vehicle or component performance (Weidig, Pivitt). The studies established the problems impacting vehicle operation and maintenance related to material failures, deficiencies or limitations and made recommendations for replacement parts made out of fiber-reinforced polymer-composites (FRPC).

The HMMWV, which is seen below in Figure 1, experienced a large amount of failures with disc brakes.

Figure 1: M1025

The three different medium tactical vehicles that failures were researched on were the M35A2, the M939 and the M923. The M35A2 is a 2.5 ton truck which is shown in Figure 2. Failures on this vehicle included spring assembly, the cab and related parts. Both the M939 and M923 5 ton truck series experienced failures with the cab and related parts, radiator and engine mount, frame cross member cracking and the suspension system (Weidig).

Figure 2: M35A2

The HEMTT is a 10 ton truck, displayed in Figure 3, which experienced failures with the service brakes, driver

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and passenger seat assemblies, fasteners, and joint incidents (Weidig).

Figure 3: HEMTT M977/M985

Additionally, the Army wanted to increase component life and reduce life cycle cost for the Abrams battle tank, shown in Figure 4. Problem areas included track pad and torsion bar life. As a result, 49 of the Abrams components were examined to determine the feasibility of using advanced materials instead of steel (Pivitt).

Figure 4: M1A1

The causes of these failures amounted to corrosive environments, vibrations, fatigue loading, impact loading and torsion loading. Therefore the mechanical properties of the FRPC must be superior to those of traditional steel and aluminum (Pivitt).

COMPOSITE RESEARCH

A composite is a material that is composed of two or more distinct, structurally complementary substances which combine to produce structural or functional properties not present in any individual component (www.dictionary.com). In this case two components are considered: a fiber-reinforcement along with a polymer-matrix.

Fiber-Reinforcement

The fibers researched consisted of fiberglass, carbon, graphite, aramid, and polyethylene. Fiberglass is typically used to aid in the optimization of mechanical properties for complexly loaded components (See Figure 5). Fiberglass may come in the form of woven roving or chopped fiber. It may be used in knitted or braided performs allowing for a high amount of glass reinforcement in the composite. Pound for pound, fiberglass is stronger than steel or aluminum (Weidig).

Carbon or graphite fibers have high strength-to-weight and stiffness-to-weight ratios and provide excellent fatigue resistance (www.hexcelschwebel.com).

Aramid and polyethylene fibers are good for weight critical applications and are usually used in structural components as hybrid reinforcements (See Figure 5) (Weidig). An example of an aramid fiber is Kevlar, which is five times stronger than steel, weight for weight (www.hexcelschwebel.com). Kevlar has great impact resistance and is an extremely light structural fiber. It has applications that include personnel protection vests, helmets, and spall liners. An example of a polyethylene fiber is Spectra, which is "ultra lightweight", has a high damage tolerance, UV resistance and high strength. Its applications include ballistic and high impact composite applications (www.hexcelschwebel.com).

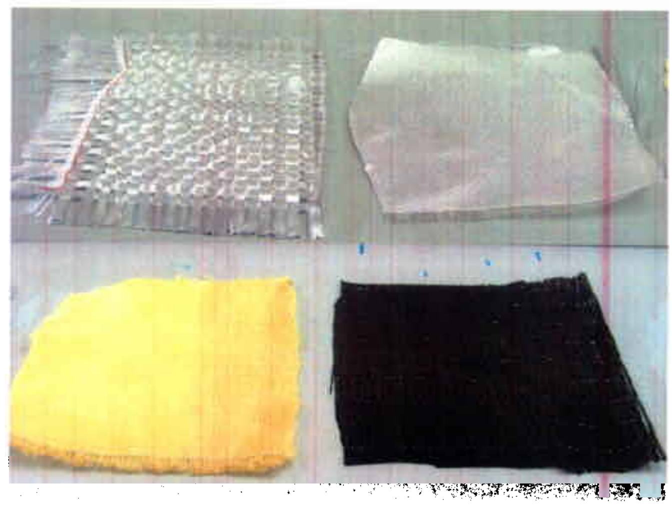

Figure 5: Top: 24oz (left) and 8oz (right) S-2 fiber glass. Bottom: Kevlar (left) and Graphite (right)

Polymer-Matrix

The types of polymers researched for the resin-matrix were broken down into two distinct categories: thermosets and thermoplastics. Some examples of thermosetting resins looked at by the Army are: epoxy, phenolic, polyester and vinyl ester. Polyester and vinyl ester have been traditionally used for nonstructural and sub structural applications and are cheaper than epoxies (Weidig). Epoxies are the most widely used matrix resin for structural composites. Epoxies are chosen due to their high mechanical properties, good adhesion to fiber reinforcements and low cure shrinkage. The only downside is they are expensive. Also available are epoxies that can withstand continuous exposure to temperatures above 350°F, whose application includes engine components (Weidig).

Thermoplastic resin-matrices are restricted to secondary structural or nonstructural components. Thermoplastics are resistant to damage, can be joined with adhesives, and some have good dimensional stability. They also do not require catalyst reactions or refrigeration as do most thermosets and can be recycled which reduces waste and lowers manufacturing costs (Weidig). Some examples of thermoplastic resins are polypropylene, polyethylene, nylon and polyvinyl chloride.

A positive note regarding both thermoset and thermoplastic resins as stated by Weidig is that "Developments in both thermoset and thermoplastic resins have resulted in improved retention of mechanical properties in hot, humid environments." This is important for Army vehicles since several wars have been fought in this type of climate.

The most important objective to remember when choosing a fiber-reinforcement and a polymer resin is to choose materials that are compatible with one another. The purpose of this is to obtain maximum adhesion between the fiber and matrix materials (Weidig). The following figure displays two different FRPC's.

Figure 6: Left: S-2 glass/epoxy. Right: Graphite/Epoxy

Coatings and Adhesives

Coatings play an important role in composite structures. Metals require coatings to prevent corrosion. Corrosion protection is not obligatory for polymer composites (Pivitt); however coatings may be necessary for any of the following reasons:

- Moisture absorption – moisture may result in dimensional changes and cause undesirable internal stresses inside the material (Jang)
- A porous surface
- To protect the composite from solar degradation
- Decrease flammability potential
- Aid in protection from NBC

Adhesives are used to bond different types of composites to one another. This may be necessary when designing a hybrid composite. Typical adhesives used include epoxies, urethanes, acrylics, polyesters and polyimides (Weidig, Hunston). These adhesives exhibit properties such as high modulus, low creep, and handle high temperatures. However, some of these materials are brittle (Huston).

Epoxies are the preferred adhesive for structural and sub structural components. This may be because the bonding surface of the polymer requires little preparation prior to bonding (Weidig). The next adhesive mentioned was urethane. Urethanes provide impact resistance over a large range of temperatures. They also have the ability to bond together dissimilar materials such as thermoset and thermoplastic composites (Weidig). Another adhesive mentioned was acrylic. It was found through research that acrylic adhesives provide only a small amount of applications in tactical truck components due to the reduction in shear strength at slightly elevated temperatures (Weidig).

As a result of the composite research performed, it was found that fiber-reinforced polymer-matrix composites provided greater performance than metallic components by (Weidig, Pivitt):

- Significantly reducing the weight thereby improving mobility
- Improving mechanical properties
- Extending part life and increasing reliability without compromising vehicle and/or component performance
- Increasing stability in a number of hostile environments over a large time span
- Reducing the amount of maintenance
- Reducing life cycle costs due to parts consolidation

POLYMER COMPOSITE APPLICATIONS

Using the information collected on fiber-reinforced polymer-matrix composites, recommendations were made as to what truck components could benefit from the usage of FRPC's rather than steel or aluminum. The following components were recommended for replacement in the study performed by AM General:

HMMWV: cargo floor, footwells, rear quarter panels, tailgate, drive shaft, bumpers and supports, and crossmembers.

M35A2, M939, M923: cab assembly, hood and fender assembly, instrument panels, crossmembers, bumpers and supports, wheels, leaf springs, torque rod, drive shaft, and seats.

There were no recommendations made regarding the HEMTT.

For the Abrams study, 22 out of 49 components were recommended for replacement. The following is a list of only four of the composite design concepts (Pivitt):

Air intake plenum:

	standard	composite
material	aluminum	nylon and polyester/E-glass
weight (lbs)	211	65
cost ($)	4305	551

Table 1: Data for Air intake Plenum

Final drive hub:

	standard	composite
material	steel	epoxy/graphite/S-glass
weight (lbs)	380ea	190ea
cost ($)	1502	1100

Table 2: Data for Final Drive Hub

Hydraulic oil reservoir:

	standard	proposed material
material	aluminum	Cross-linked polyethylene
weight (lbs)	29	19
cost ($)	750	185

Table 3: Data for Hydraulic Oil Reservoir

Turret platform:

	standard	composite
material	aluminum	polyester/E-glass/honeycomb
weight (lbs)	287	180
cost ($)	1719	1235

Table 4: Data for Turret Platform

COMPOSITE ARMORED VEHICLE ADVANCED TECHNOLOGY DEMONSTRATOR (CAV ATD)

The CAV is a great example of a military ground vehicle constructed out of composite materials. Some of the objectives of CAV according to United Defense L.P. were to "Demonstrate the robust integration of composite structures and advanced lightweight armors into an affordable advanced technology demonstrator." CAV combined structure and armor and provided a weight reduction of at least 33% (UDLP). Figure 7 displays the front quarter section of the CAV.

An important consideration in material selection was the material performance at elevated temperatures. The materials were thermally tested at a maximum temperature of 160°F and a minimum temperature of -65°F, although higher temperatures are better known to cause problems in composites than lower temperatures. Ballistic performance was an also a major concern with respect to extreme temperatures (Ostberg).

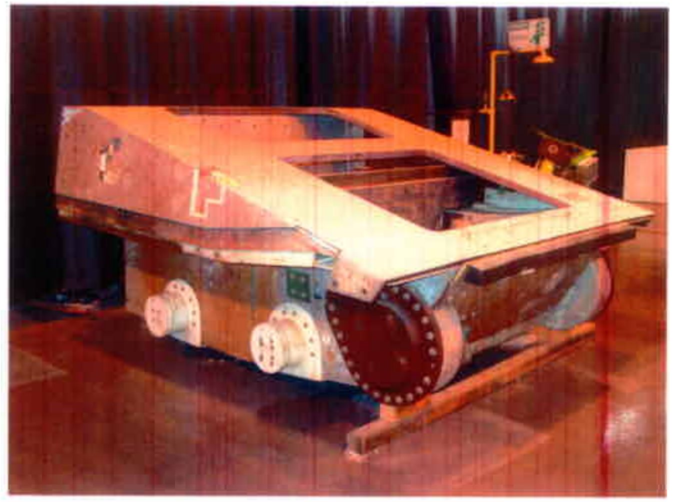

Figure 7: CAV hull quarter section

Three main sections were designed utilizing composites. These sections are the upper hull, the lower hull and the crew capsule and bulkheads.

<u>Upper Hull</u>

The upper hull is comprised of three layers which are fabricated using an automated fiber placement (AFP) process. The inside surface of the structure uses a layer of epoxy composite designed with smoke and flammability properties in mind. The middle, integrated armor layer consists of ceramic tiles bonded with a resilient adhesive to a backing material (UDLP). The adhesive used aids in reducing shock and fracture. The outer surface is made out of epoxy and S-2 glass. This layer "Improves multi-hit performance, resists day-to-day wear and tear, mitigates environmental exposure and reduces maintenance" (UDLP).

<u>Lower Hull</u>

The lower hull includes two different components that use composites. The first component, the tub structure, is a sandwich construction made of an S-2 glass composite. This construction provides greater weight-to-stiffness performance and works well as a mine armor (UDLP). The tub is fabricated using a hand lay-up with an autoclave cure using thermoset prepregs. The second component is the sidewall which is also made from an S-2 glass composite. It is fabricated using a thermoplastic diaphragm forming process (UDLP).

<u>Crew Capsule and Bulkheads</u>

Once again there are three main components: roof, base and bulkhead. The roof is a multi-layer laminate made using metal and the following composites: phenolic resin with S-2 glass and epoxy resin with S-2 glass. This laminate provides spall, flammability and armor protection (UDLP). The base and bulk head were designed using sandwich construction. This composite is made using phenolic resin and S-2 glass with a balsa wood core. This design is cost effective and meets flammability requirements (UDLP).

Conclusions from CAV Program

- Polymer composites are a practicable candidate material for use in Army ground vehicles. They display high strength, robustness, and provide significant weight reduction over metal counterparts.

- Polymer composites can handle military vehicle requirements such as cross country terrain loading, noise reduction, impact resistance and in field reparability.

- Polymer composites are capable of handling all types of environmental conditions including: NBC agents, corrosion, flammability and extreme temperatures.

- Cost modeling showed that polymer composites are affordable compared to metallic structures. Additionally, logistic supportability was defined and does not require any new military occupational specialties (MOS's).

- VARTM was found to be a viable method for composite fabrication.

(UDLP)

CURRENT TECHNOLOGY

Over the years it has been extremely difficult to convince Program Managers as well as high level military officials that polymer composites should be implemented in ground vehicles. Program officials like to stick with what works and is cost effective. If a polymer composite has greater performance, but dollar-for-dollar is higher cost compared with steel, the more cost effective option will be chosen. The primary concern for program managers is the end item cost, not the life cycle cost (Ostberg).

The major obstacle that composite enthusiasts are trying to overcome is the lack of knowledge of advanced materials in the ground vehicle community (Pivitt). Vehicle requirements however are changing, and the need for a lighter weight solution is here. In the past heavier vehicles were considered better. Vehicles were already positioned in Germany and around the world, ready to deploy by land when needed. Today, troops, vehicles and equipment are to be kept stateside and deployment occurs by air instead of ground (Ostberg). See Figure 8.

Figure 8: HMMWV Deployed using Helicopter

Vehicle weight reduction becomes a major issue because the method of deployment, for example, cargo planes, can only carry so much weight. Hybrid composites, using polymer composites along with ceramics become the perfect light-weight high performance solution.

An example of the weight issue can be illustrated with the HMMWV. The uses of the HMMWV have changed over the last decade. In Operation Iraqi Freedom (OIF) HMMWV's are participating in convoys and other vehicle operations in areas where ballistic protection is inherent to the soldiers survival. Armor Survivability Kits (ASK) are now being added to HMMWV's to protect them against ballistic threats. This armor is made out of steel which is adding over 1200 lbs to the vehicles. As a result, the vehicle is much slower, has engine and suspension problems and the overall vehicle life is greatly reduced. The advanced materials and manufacturing center at the U.S. Army Tank-Automotive Research Development and Engineering Center (TARDEC) along with various contractors have fabricated several prototype composite door alternatives for the HMMWV in response to the weight problem. The doors have been sent to several Army conferences around the United States to show military as well as industry officials that lighter, high performance options are available. A sample composite door is shown below:

Figure 9: Composite HMMWV Door Equipped with Ballistic Window

Presently, there are only two accepted and used polymer composites in Army ground vehicles. The first is the hood of the HMMWV. The HMMWV hood was originally designed for steel. However, due to the airlift requirements, there was a need for a weight reduction and the hood was the component chosen for replacement. The new hood (Figure 10) was fabricated using the same configuration as for the steel hood, but was made from sheet molding compound (SMC). This composite hood however, has experienced a high failure rate. Engineers are currently working to redesign and resolve the issues with this composite hood (Ostberg).

Figure 10: HMMWV Composite Hood

The second use of polymer composites currently is spall liners. When vehicles undergo a ballistic event, small fragments from the bullet may break off and penetrate inside the occupant compartment of the vehicle. To protect from this, a spall liner, anywhere from 0.25 in to 1 in thick, is placed on the inside of the vehicle walls. These spall liners are typically made from S-2 glass or aramid with a phenolic (non-flammable) resin matrix (Ostberg). Some spall liners may also use small amounts of ceramics, which adds more weight. Spall liners have a few other functions including good flammability properties, and providing noise reduction. Spall liners are included on all M113's and M577's which can be seen below in Figure 11, as well as many other ground vehicles.

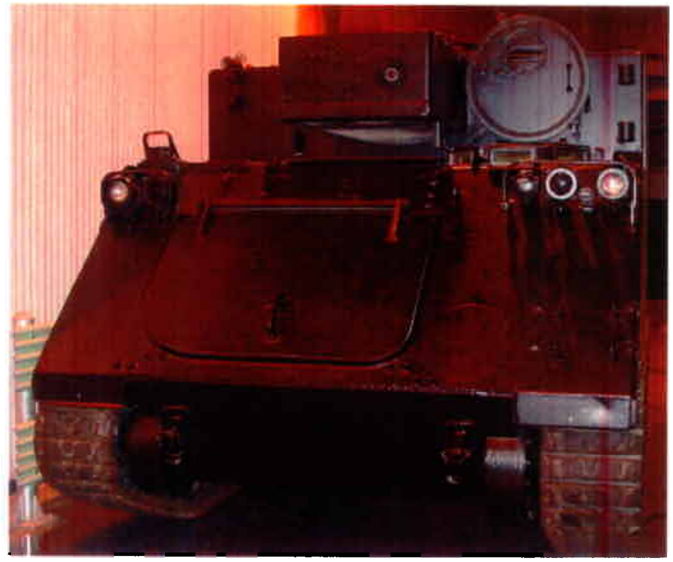

Figure 11: M577 Equipped with Spall Liner

RECENT RESEARCH AND STUDIES

A couple of different studies were conducted by Army Research Laboratory (ARL) in the past few years. The first study focuses on Co-Injection Resin Transfer Molding (CIRTM). Before CIRTM, hybrid composite layers were made separately and then bonded together to form the hybrid composite (Fink et al) [6]. The CIRTM process is similar to VARTM except that in CIRTM, "Two resins are simultaneously injected into a mold filled with a stationary fiber bed and are co-cured," (Fink et al) [6]. Multiple resins are usually required for composites to attain desirable properties. This new process enables an engineer to fabricate multi-layer hybrid composites with only a single step process. As a result, manufacturing costs are reduced, and there is improved structural quality and performance due to the co-cure (Fink et al) [6]. In this case to test the process, a glass-reinforced vinyl-ester/phenolic composite was fabricated (See Table 5 below for description of qualities). The end item is a combination of the good and bad qualities, the good negating the bad.

	Good Qualities	Bad Qualities
Vinyl-ester	low cost, good mechanical properties, reliable processing	extremely flammable, produces toxic smoke upon combustion
Phenolic	low cost, outstanding fire, smoke and toxicity protection	poor mechanical properties

Table 5: Qualities of Two Co-Injection Molded Resins

The second study performed by ARL focused on "Cost-Effective Manufacturing of Damage-Tolerant Integral

Armor." In general, the recipe for integral armor includes the bonding of ballistic armor tiles, composite structure, spall liner and a nuisance cover. For this study the spall liner was made with a phenolic resin because of its fire, smoke and toxicity protection. The rest of the armor was made with epoxy resin to improve the structural performance (Fink) [4].

CIRTM was used as an alternative to the multi-step VARTM process to create a multifunctional composite structure. Stitching of the composite in the through-the-thickness direction was used to improve multi-hit ballistic performance. Both CIRTM and stitching were used to (Fink) [4]:

- Provide pollution prevention benefits

- Result in a tougher interface between different layers when compared with manufacturing layers separately, such as with the VARTM process, and later bonding the separate components together

- Reduce the cost of the armor

- Enhance the damage tolerance of the material

Another objective of this study was to provide ballistic properties of lower cost, "VARTM/CIRTM process friendly" resin systems. The resins tested were vinyl-ester, epoxy and a polyester prepreg baseline. S-2 glass was used as the fiber-reinforcement (Fink) [4]. The panels were tested with and without stitching. Ballistic testing was done with a 0.50 cal fragment-simulating-projectile (FSP) at a velocity of 1,550 fps. Results showed that equivalent ballistic performance was demonstrated by the vinyl-ester and epoxy resins when compared with the prepreg baseline, only at a reduced cost. The stitching reduced the delamination of the composite (Fink) [4].

A study was performed by Vinay Gupta at the Aichi Institute of Technology in Japan on carbon/PEEK (Polyether Ether Ketone), Kevlar/PEEK thermoplastic composites. Some of the advantages of thermoplastic composites are the reduction in fabrication costs, improved damage tolerance, repairability, high impact strength and reduced moisture absorption and degradation. Gupta mentions that, "The choice of thermoplastics over thermosetting resins offers the possibility of producing fiber-reinforced composites with enhanced resistance to matrix cracking." This is because the strain to failure of numerous thermoplastics is typically 50-100% compared to 1-2% for thermosetting resins like epoxies (Gupta).

Gupta fabricated carbon/Kevlar/PEEK composites to determine their mechanical properties, impact strength and fracture energy. The matrix resin, PEEK, was used in powder form. The composites were fabricated using a matching mold dye in a press.

Results showed that the Kevlar had poor mechanical properties compared to that of the carbon. This was due to the poor adhesion of the Kevlar fabric to the PEEK resin matrix. The lack of adhesion between the matrix and the fiber in the Kevlar part resulted in a very low fracture energy, while the impact strength for both the carbon and Kevlar was the same. The applications for the carbon/PEEK composite include blast protection, structural materials, and applications requiring high fracture energy (Gupta).

TARDEC completed a study in 2002 regarding the replacement of HMMWV Soft Top or canvas doors with durable polymer composite doors. Replacement of the door was needed due to problems encountered such as leaking, puncturing, and reduced window visibility (Filar). The new doors were meant to be used in areas in and around military installations, in non-hostile environments, therefore ballistic protection was not a requirement.

The resin matrix material chosen was a thermoset, polyvinyl-ester. This resin was chosen because of its lightweight and high strength properties. Methyl Ethyl Ketone Peroxide (MEKP) was also used in the manufacturing process as a catalyst to the resin. The fiber reinforcement used was chopped strands of S-2 fiberglass due to its stiffness and low cost. The reinforcement supports loading and limits door deformation. It also provides corrosion resistance and creep resistance of the overall composite (Filar).

The composite was fabricated using a chopper gun, which sprayed a mixture of resin, catalyst and chopped fiber into the door mold. Upon fabrication, the door was assembled with hinges, a window, door handle and a seal. The door was then fitted-up on a HMMWV. This study proved that a composite door is a low cost, high strength alternative to the traditional canvas door (Filar).

THE FUTURE OF FIBER-REINFORCED POLYMER-MATRIX COMPOSITES

As previously mentioned, the air transportability weight limitations will force the Army to begin to use, and accept composites in tactical vehicle applications. The requirement is that any new vehicles made must be transportable with a C130 aircraft, which holds no more than 18 tons (Ostberg). Both the Future Combat Systems program and the Future Tactical Truck Systems program will provide the newest, state-of-the-art vehicles to the Army.

FUTURE COMBAT SYSTEMS (FCS)

FCS will be unlike any other military vehicle to date. It will provide ballistic protection superior to the Abrams and contain advanced weaponry and communication systems. The CAV ATD was a stepping stone to the FCS and like the CAV, FCS will combine structure with armor (Ostberg). One of the goals of FCS is to reduce the structural/armor weight by 10 to 15 percent. The maximum weight that the FCS may weigh is 18 tons, so it can be transported by a C130 aircraft.

Vehicle life is also a major factor for FCS. Miles driven in peace times average only hundreds of miles per year, while in wars times a vehicle is driven an average of 1500 miles per month. The vehicle life expectancy for FCS however, is 37,000 miles which is an extremely large amount when compared with all other ground vehicles. The Bradley fighting vehicle, for instance, was designed for a life of only 6,000 miles (Ostberg).

Temperature is an important consideration for FCS. Desert conditions subject vehicles to solar loading as well as heat and humidity. Even when vehicles are stored in these conditions out of direct sunlight, temperatures can remain extremely high. The other extreme is artic conditions. This is why the materials used for FCS will be tested for a temperature range of 180°F to -60°F (Ostberg).

Composite Hybrids and Manufacturing

Hybrid composites are being researched and tested for potential use in FCS. The right combination of different materials with different properties will yield a composite with many advantages over traditional materials (Fink et al) [6]. These hybrids may be composed of several different types of advanced materials which may or may not include fiber-reinforced polymer-matrix composites, ceramics, rubber, adhesives and some type of metallic component. Considerations for the vehicle space frame range from aluminum to composites (Ostberg). A picture of the FCS space frame is illustrated below in Figure 12.

Figure 12: Full Space Frame Design

Several different hybrid composite recipes are currently being tested. Some of this work, which is being performed by the Lightweight Structures team at TARDEC, utilizes the VARTM process to make hybrid composite components. Figure 13 displays a picture of the VARTM process.

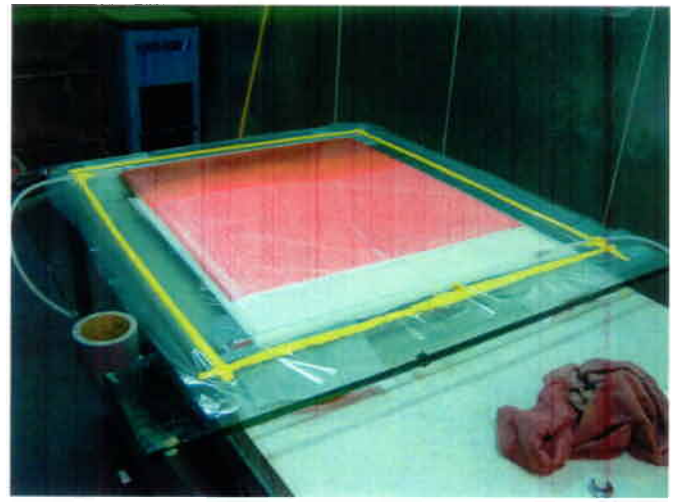

Figure 13: VARTM Process – Resin Infusion

Once all of the components are made, the layers are adhesively bonded under vacuum and cured. The final product is a test sample which will be used to characterize the mechanical and thermal properties of the material. Several different beam "recipes" are being tested to determine a material baseline for FCS.

FUTURE TACTICAL TRUCK SYSTEMS (FTTS)

The purpose of FTTS is to provide vehicles to support FCS. FTTS consists of two versions: FTTS-Maneuver Sustainment, and FTTS-Utility. Technologies that will be researched in this effort include:

- A lightweight advanced structure, which will increase payload to weight ratios, mobility and transportability
- Enhanced vehicle survivability through integral and modular armor

Crew survivability will be greatly increased using subsystems that provide an integrated mine/ballistic protection, as well as NBC and ambush protection.

CONCLUSION

Research, both past and present, has shown that FRPC's are a viable option for use in Army ground vehicles. The use of composite components, structure and armor results in a high performance, low cost solution, superior to that of metallic components, structure and armor. The two current uses of polymers, the HMMWV hood and the spall liner, are just the beginning of the fielded applications for composites. FCS and FTTS is where the opportunity lies for the future of fiber-reinforced polymer-matrix composites.

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

AFP – automated fiber placement

ASK – armor survivability kits

CAV ATD – composite armored vehicle advanced technology demonstrator

CIRTM – co-injection resin transfer molding

FCS – future combat systems

FRPC – fiber-reinforced polymer composite

FSP – fragment simulating projectile

FTTS – future tactical truck systems

HEMTT – heavy expanded mobility tactical truck

HMMWV – high mobility multipurpose wheeled vehicle

MTV – medium tactical vehicle

M1A2 – Abrams third revision

M1025 – HMMWV

M35A2 – 2.5 ton truck from medium tactical vehicle family

M939 – 5 ton truck from the medium tactical vehicle family

M923 – 5 ton truck from the medium tactical vehicle family

NBC – nuclear, biological, chemical

OIF – Operation Iraqi Freedom

PEEK – polyether ether ketone

TARDEC – Tank-Automotive Research Development Engineering Center

UDLP – United Defense Limited Partnership

VARTM – vacuum assisted resin transfer molding